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PROBLEMS OF APPROACH DURING POOR VISIBILITY

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Introduction

Although many blind landings have been made so far in various countries, there has never been any system safe enough to permit all-weather landings of airline planes, in spite of all the advantages which such landings would present. A first step towards a solution of the problem has been taken by the construction and wide use of the ILS system (Instrument Landing System). It is obvious, however, that this system has not been conceived for all-weather landings, but only as an aid in guiding pilots to runway visibility. The ILS system defines the localizer axis to within $\pm 1/3$ of a degree with respect to the runway axis, which leads to too great a tolerance on the lateral error. /407

The ILS localizer antenna is located at the end of the runway, and, for jet airplanes, the runway can be up to 3 km long. A $\pm 1/3^{\circ}$ error leads therefore to a lateral tolerance at the ground contact point of the order of ± 20m, and this figure is considered unacceptable. It therefore appears logical to try to improve the ILS azimuthal precision, and tests along these lines have led to the conclusion that such improvement is possible. However, another fault inherent to the ILS system has appeared, and that is the one due to the azimuthal radiation lobes which have a maximum between 20° and 30° with respect to the horizontal. A landing airplane is seen by the ILS localizer within a very small angle and consequently receives little energy. Another airplane, flying above the airport and located at the lobe maximum, can then reflect to the landing airplane an energy of the same order of magnitude as that which the latter receives directly. The interferences which are thus produced lead to spurious axes. The goal reached by the CSF (Compagnie Générale de Télégraphie Sans Fil; General Wireless Company) system is the definition of a glide axis similar to that of the ILS system, with a greater azimuthal plane precision and without the possibility of interference troubles.

Description of the CSF System

The glide axis is defined by the intersection of a localizer plane, which goes through the runway axis, with a glide plane inclined 2° or 3° with respect to the horizontal. Each plane is defined by the equi-signal fields radiating as two diverging lobes. There are, therefore, four lobes. Each lobe could be produced by a special antenna. As a matter of fact, the two azimuthal lobes are produced by two parabolic antennas which are located on either side of the runway, whereas the two site lobes are produced by the same parabolic cheese-type antenna with two separate exciters. /408

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The emitted frequency is the same for all four lobes. It has been chosen of the order of 1200 Mc/s in order to be in the band allocated for blind landings. In addition, this frequency leads to the possibility of having thin lobes of appropriate patterns, with antennas of reasonable dimensions. Thus, with parabolas 3.6 m high and 1.5 m wide, a lobe with an 8° in site aperture is obtained, and the lobe drops off smoothly in azimuth towards the runway. With a cheese antenna 4.2 m high and 30 cm wide, a 7° in site aperture lobe has been produced. The polarization of the emitted signal is vertical because experience has shown that this type of polarization minimizes changes due to ground influences. The four lobes are made distinct from each other by means of four modulations, each lobe having its own modulation. The modulation frequencies are 20, 24, 30 and 34 kc/s for the left, right, top and bottom lobes respectively. The transmission cycle is as follows:

The carrier is modulated at the lobe characteristic frequency and is directed, by a rotating microwave switch, to the transmitting antenna corresponding to the lobe in question. This transmission lasts approximately 10 msec and the switching frequency is 10 cps. The switching of the modulation signal is of course done in synchronism with the signal fed to the antenna. A superheterodyne-type receiver, installed inside the airplane, consecutively receives a 1200 Mc/s carrier which is square wave modulated at 20, then 24, 30 and 34 kc/s. After frequency change and intermediate frequency amplification, the detected low frequency signals are separated by low frequency filters and in turn detected. The resulting dc currents are proportional to the received field amplitudes and are compared two by two in a cross-needle indicator similar to the more common ILS type.

Performance of the Apparatus

The range corresponding to a transmitted power of 10 W has been found experimentally to be of the order of 100 km, which insures finding the axis at distances encountered in normal landings with a large safety factor. An azimuthal angle of $\pm 45^{\circ}$ is covered without spurious axes. At a certain altitude the spurious axes show up for such high inclination angles that there is no doubt as to their being spurious. Otherwise it is impossible to intercept them with normal landing procedures. The sensitivity of the airplane indicator is such that the azimuth needle is pinned for a 2.5° deviation with respect to the axis, for airplane to contact point distances exceeding 5 or 500 m.[1] For smaller distances the reading becomes a function of the distance error

1 Translator's note: These numbers are the original ones in the text.

with respect to the axis and to the contact point, and the needle is pinned for 30 m deviations. Since the pilot can easily make out readings of better than one sixth of full scale, the precision is 6 m when using manual control while landing. This deviation can very likely be reduced to one-half by an automatic pilot. The site needle is pinned for a deviation of 0.5° above the axis and 0.4° below. /409

Automatic approach tests were made in 1956 under the sponsorship of the Service Technique des Télécommunications de l'Air Françaís (French Air Force Telecommunications Technical Service), and these yielded an average deviation of $\pm$ 1 m in altitude and $\pm$ 5 m laterally with respect to the glide axis at a distance of 600 m from the theoretical contact point. These tests were not meant to carry out completely automatic landings and the manual control was generally resumed when the airplane was at an altitude of about 10 meters. The encouraging results led to consideration of the next logical step, which is the use of the system as an all-weather landing system. Tests are presently in progress, and the principles developed by the Blind Landing Experimental Unit (BLEU) are being applied.

Use of the System for All-Weather Landings

Review of the Principles Developed by BLEU

According to a great number of tests undertaken in England by specialists in blind landings the steps to take are the following:

Down to 60 feet altitude the airplane follows a straight glide axis which lies in a vertical plane going through the runway axis and which lies at 2° or 3° from the horizontal.

From 60 feet down the airplane must be maintained in the runway axis plane and must come down following an appropriate curve. When the airplane gets to a 20 foot altitude the possible drift which is due to a transverse component of the wind is corrected and the airplane lands following the trajectory defined before.

There are therefore three schematic and natural steps and in order to go through these steps the following solution has been adopted.

Solution Tried by BLEU

Step 1. This step is divided into three parts. Down to 300 feet altitude the glide axis is furnished by the ILS system. Below 300 feet the ILS precision is not sufficient in the azimuthal plane. The axis is defined by the ILS glide path and a vertical plane which is due to the radiation of two feeder (leader) cables on each side of the runway.

At 300 feet the switching between the two reference vertical planes is automatically insured by an FM radiometer. The glide path still guides the airplane down to an altitude of 100 feet, beyond which it becomes impossible to use the glide path in certain locations. The airplane continues on its previous course down to an altitude of 60 feet.

Step 2. The curving is done by the radiometer and the airplane remains in the runway median plane with respect to the landing cables.

Step 3. The altimeter gives a signal of correction with respect to the runway compass direction and the airplane finally lands with the /410
help of the FM radiometer and the magnetic compass.

This series of maneuvers has three points which are capable of improvements. These points are the following:

The device is designed with two azimuthal guidance systems.

The setting up of guiding cables might cause difficulties in certain areas with regard to obtaining lots or to the installation proper (for example, on lots which lie along the sea shore).

At the end of the first step (and for approximately 4 seconds) the airplane has no glide path information.

Possible Solution With the Help of the CSF Device

The device developed by the CSF company permits the airplane to exactly follow the three landing steps.

Step 1. The airplane is located at approximately two to three kilometers from the runway start with an axis inclination usually encountered at 300 feet altitude. There are, therefore, no range problems for the system radio transmission and the plane can start the landing procedure at the predetermined point without difficulties. The localizer precision is sufficient up to 60 feet altitude so that it can be utilized fully during the first step, with no need for switching to an additional aid (leader cables). Also, the choice of a 1200 Mc/s transmission frequency affords a pronounced attenuation of the ground influences at the landing facility location. In this way the glide path is certainly less distorted by ground effects than in the case of UHF transmission, and remains correct down to approximately 30 feet from ground. Consequently the airplane can follow, during the entire course between 300 feet and 60 feet altitude, the axis defined by the two azimuth and site planes defined by the four transmission lobes described above. The possible drawback which might be caused by the use of any additional device to the ILS system, and the presence of the "hole" between 100 and 60 feet, are thus avoided.

Step 2. Since the glide path remains correct down to an altitude of 30 feet it is necessary as a safety factor to keep the switching to 60 feet on the curve defined by the radiometer. The localizer plane remains usable, however, during the entire step 2, namely, down to an altitude of 20 feet. During the time corresponding to this step the airplane is low and the interference reflections on other airplanes flying in the maximum axis of the localizer lobe (known fault of the ILS System) are harmless since this lobe is of low altitude and is produced by high directivity antennas.

Step 3. The lateral wind drift correction and the termination of the landing are performed as for the BLEU experiment, independently of the CSF system.

The use of this system therefore permits carrying out the three theoretical steps of smooth blind landings as defined by the Blind Landing Experimental Unit. This can be done without any special difficulties as far as installation is concerned. Experimental tests are being carried out to check these considerations with the present equipment. /411

Description of Present Equipment

The installation presently being tested dates back to 1953 and has worked in various locations without any serious trouble for more than 2500 hours.

The whole facility comprises: 1) A trailer housing the emitter, the modulator, the system which divides the power fed to the four antennas, and the control instruments; 2) Two parabolas for transmitting the lobes whose grouping defines the azimuth plane going through the runway axis; 3) A double-excitation, parabolic cheese antenna at present attached to the rear of the trailer, transmitting the two lobes whose grouping defines the site planes.

The Transmission Equipment

The carrier frequency can be chosen among six frequencies spaced 2.5 Mc/s apart and located from 1176 to 1188.5 Mc/s. The transmission frequency is controlled by a quartz oscillator which, through a sequence of multiplier and amplifier stages, furnishes a power of 4 W at 240 Mc/s to a five-fold multiplier tube (power tube 2 C 39), which furnishes the final signal. This signal is raised by an amplifier equipped with a 2 C 39 to a level sufficient to be fed to a three cavity klystron, which furnishes a final power of 50 W. The energy goes through a rotating cavity which consecutively distributes it to the four feeders corresponding to the four lobes. The radiated power is of the order of 10 to 15 W because of the presence of all the transmission elements, including the antennas. The four modulation signals are in synchronism with their corresponding UHF channels by a capacitative rotating switch synchronized with the UHF power splitter. After limiting and raising its level to a sufficient amount the modulation voltage is applied to the klystron control grid. The equality between the radiated fields is accomplished by driving part of the power fed to the right and lower exciters, respectively, to matched loads. When the installation is working the radiated power is controlled by means of detector crystals located in the antenna exciters. The modulation voltages fed by these crystals are sent to the trailer and compared two by two. The axis deviation is indicated by two zero-center meters.

Antennas

The dimensions of the reflectors, and the lobe pattern, have already been mentioned above. The gradual decrease in the sides of the azimuth patterns, when approaching the runway axis (which is necessary in order to avoid spurious axes), has been obtained by utilizing the diffraction effect of a small board panel located alongside the reflector on the runway side, and the azimuth cover is insured by a slight bending of the reflector which favors radiation in a direction close to 40° with respect to the axis.

For the site antenna and also in order to have a gradual field decrease, the cheese antenna wall facing the runway is, like the azimuth /412 parabolas, continued by a plane whose diffraction properties meet the requirements. Finally, an array of horizontal wires, located in the parabolas aperture planes, suppresses the weak horizontal components of the electric field. These components have to be suppressed because they can give rise to self oscillations when the airplane rolls with the automatic pilot on.

All the antennas can be oriented by means of screw jacks which define the site and azimuth planes with precision.

Airplane Receivers

The superheterodyne receiver has an intermediate frequency of 30 Mc/s. At the IF output and after detection the azimuth and site channels are separated by low frequency filters. In each of the two low frequency channels an automatic gain control made for each of the two channels insures the output level constancy of the two output levels to be compared. In this way measuring the amplitude differences is equivalent to measuring their ratios. At each of the two low frequency channel outputs the upper and lower and right and left components respectively are separated by two filters. The four signals thus obtained are detected and compared two by two in two moving coil indicators. The pilot must therefore pilot his airplane so that the cross point between the two needles is kept in the indicator center. The receiving antenna is a dipole imbedded in a dielectric which gives it excellent mechanical and electrical hold. A flush antenna has been made for very fast airplanes. The receiver is supplied with 400 cps, 115V single phase.

Conclusion

The instruments described above have been thoroughly tested. Their technological design can, however, be improved with respect to present technical capabilities, and, most likely, the performance can be improved. It therefore becomes possible to considerably reduce the dimensions and weight of ground equipment. The reduction can be made by replacing the klystron by a microwave triode. In addition to the gains made on the tube weight and volume, a gain is made by not having a klystron maintained at constant temperature by a flow of water (pump, wire heater, radiator, and regulating thermometer) and by not having to supply the focusing coils (current regulation and stabilization devices).

Next, the low frequency and axis control equipment can be transistorized almost completely.

Under these conditions the whole equipment can be assembled within a volume of 400 l and a weight of 300 kg, so that a trailer (8 tons) is no longer necessary.

The decrease in load achieved by the above mentioned modifications will lead to the possibility of an independent supply source as provided by a small generator set.

The progress made in the past few years on microwave antennas /413
makes possible the replacement of the bulky antennas located near the runway by antennas located right on the ground. The antennas are mechanically simpler since they do not need large pedestals. They are of wider bandwidths with respect to matching as well as pattern shapes.

The possibility for transistorizing airplane equipment is now well established. Everybody knows the advantages of lower weight, volume and supply - three expensive factors to the airplane maker - that transistors can bring. No doubt, this reduction permits the possibility of doubling, even tripling the size of the airplane receiver in order to insure total safety when used in civilian airplanes. The choice of the exact number by which one must multiply the number of airplane and ground instruments is a function of the number of breakdowns or flaws that the equipment can suffer and of the good functioning control qualities which can be associated with each device.

Possible Extensions of the Equipment Use

The principles which have been described above can be applied to frequencies exceeding the actual value of 1200 Mc/s. By going to S band for example, a considerable reduction in the antenna size can be obtained without having serious problems as far as wave propagation attenuation, still practically negligible, is concerned. By reducing the antennas they become easily orientable. This can therefore help in defining any theoretical descent axes, at the pilot's discretion, the courses still remaining straight lines.

It thus appears possible to use the same equipment for the definition of large descent angles which can be made to meet in distress cases (for example, when a fighter plane has the reactor on fire and is making a maximum dive towards the runway). Similar descent angles are also necessary for airplanes with fixed wings and with semi-vertical take-offs and landings. Finally, definitions of strictly vertical axes for rotating wing aircrafts or for aircrafts with vertical take-offs and landings are possible. This extends in principle the possibility of using the device as a landing aid to all categories of aircraft which are in existence today or are in the process of being studied.

The equipment has already proven itself in aiding regular landings and can therefore also be used to solve the problem of all-weather landings.

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